

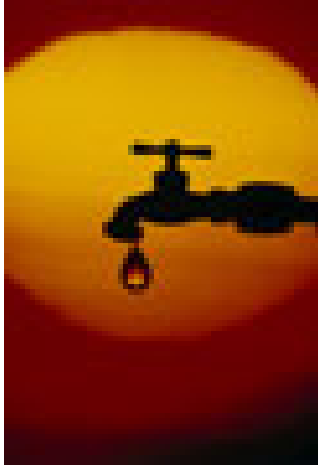
Emerging Issues for Water in the West: 21st Century Drought

Martin Hoerling and Jon Eischeid
NOAA Earth System Research Laboratory
Climate Action Panel
20 November, 2006



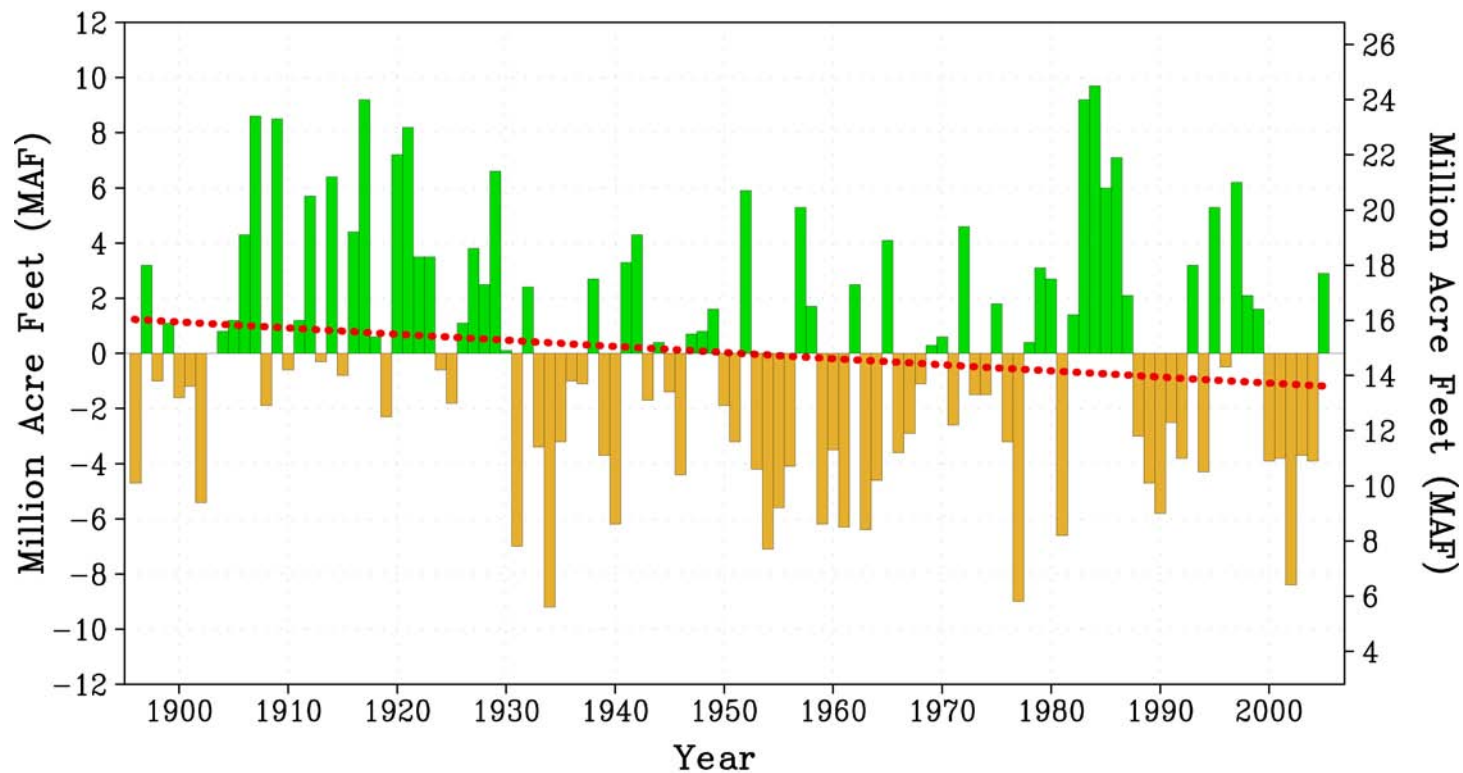
Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP





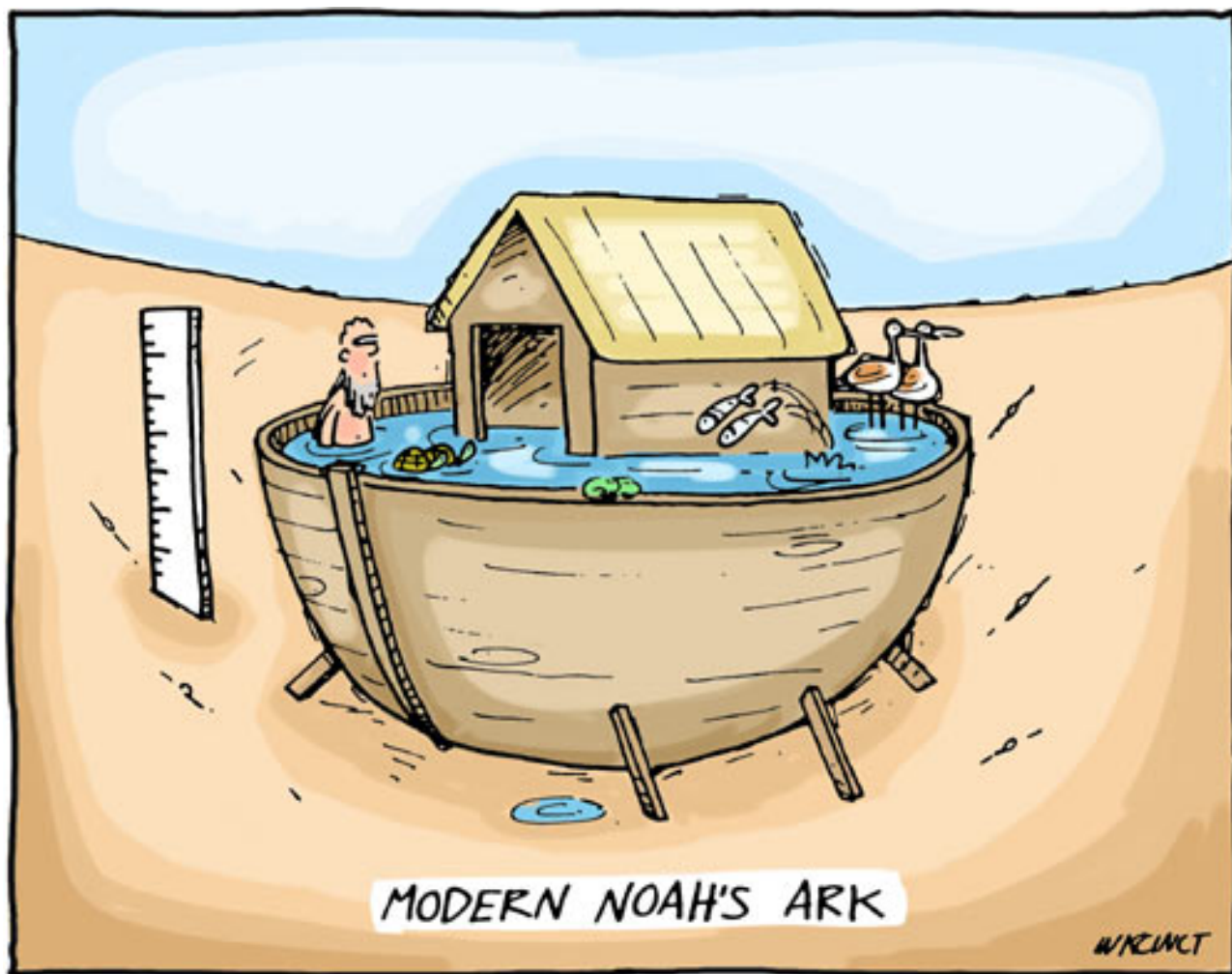
Are We Past Peak Water in the West?

Virgin Flow at Lee Ferry: 1895–2005



..... Trend = 2.2 maf/100 yr

Flow Data from Upper Colorado River Commission



21/07 2006-424 © John Ditchburn



**How Much of A
River *Will* Run Through It?**



Monthly Lake Mead Water Levels 1935-present



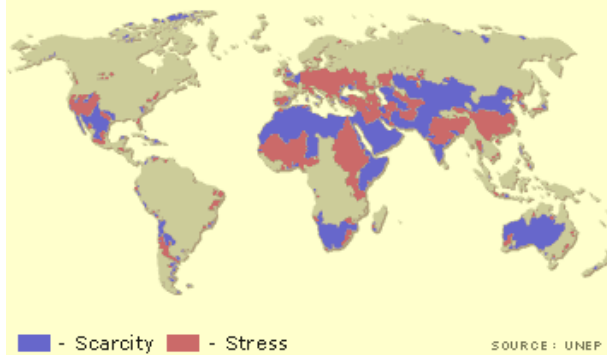


10/07 2006-401 © John Ditchburn

What Strategies for a Sustainable Future



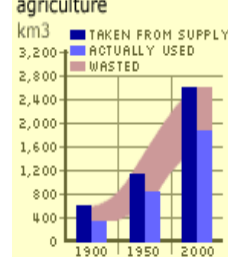
Predicted water scarcity and stress in 2025



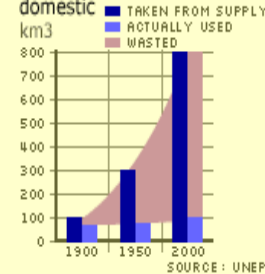
Global water use



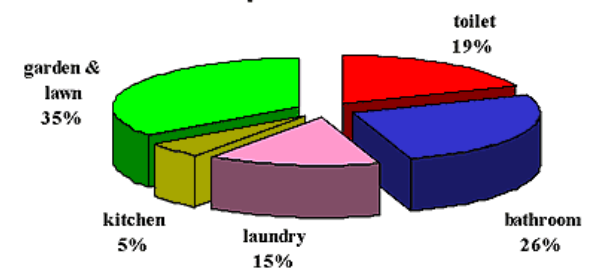
Global use and waste - agriculture

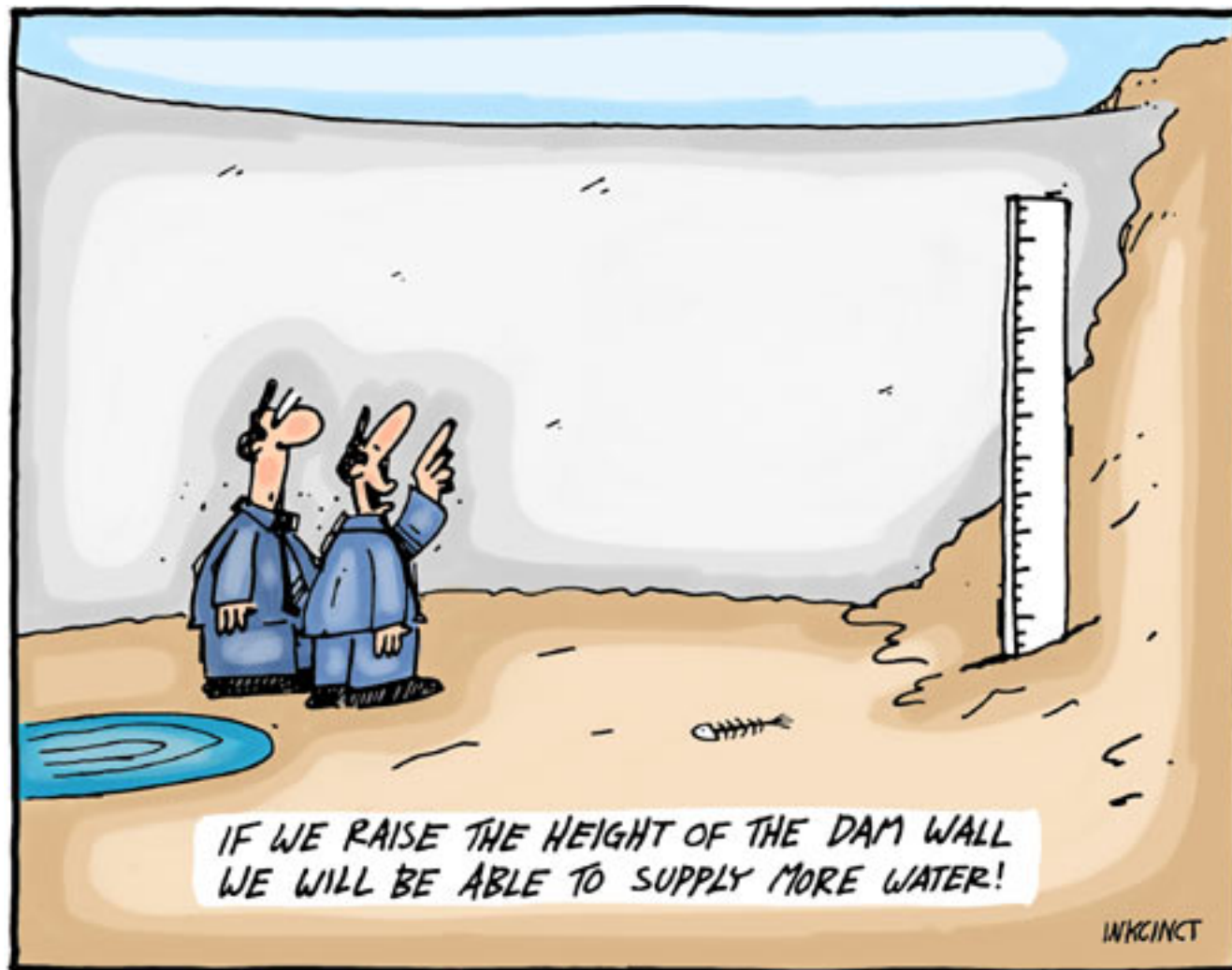


Global use and waste - domestic



Average family home consumption



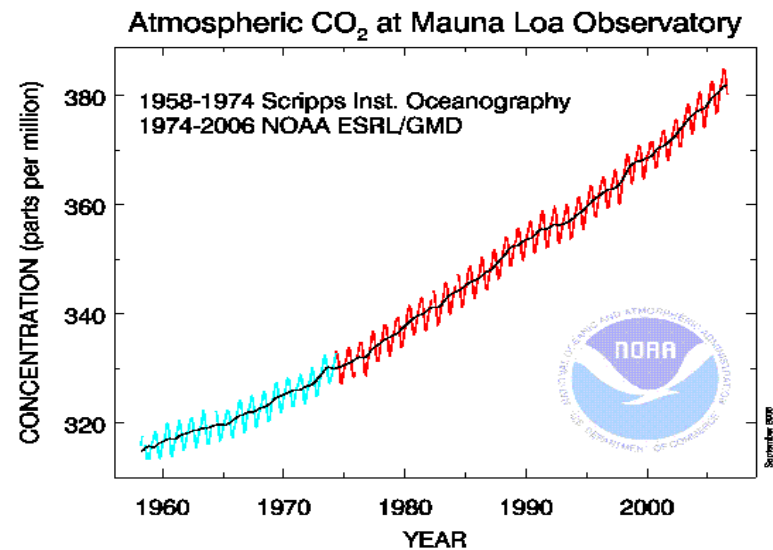
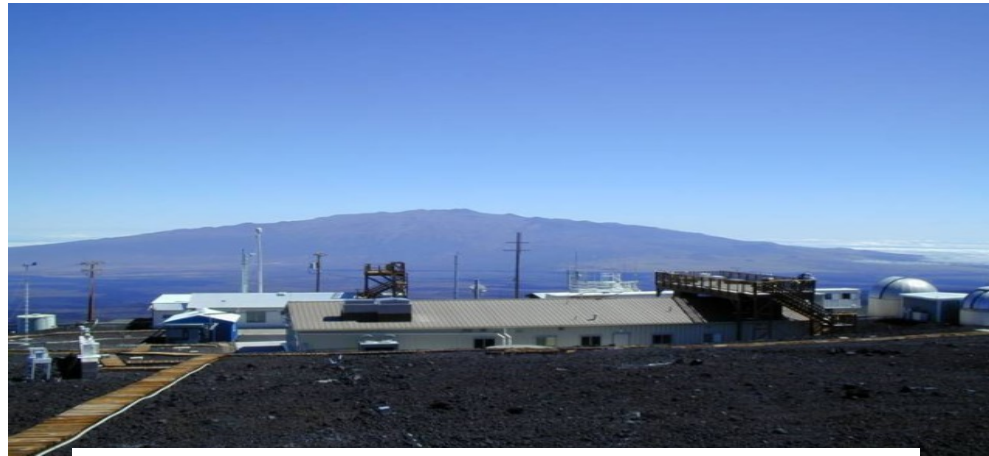


Scientific Challenges

- *What do we know about potential changes in the frequency, severity, and duration of future drought in the West?*
- *What do we know about the consequences of climate change for water in the West?*



Charles Keeling, climate scientist at the Scripps Institution of Oceanography from 1956 until his death, was considered the world's leading authority on carbon dioxide in the atmosphere.





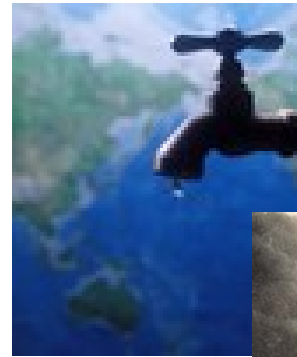
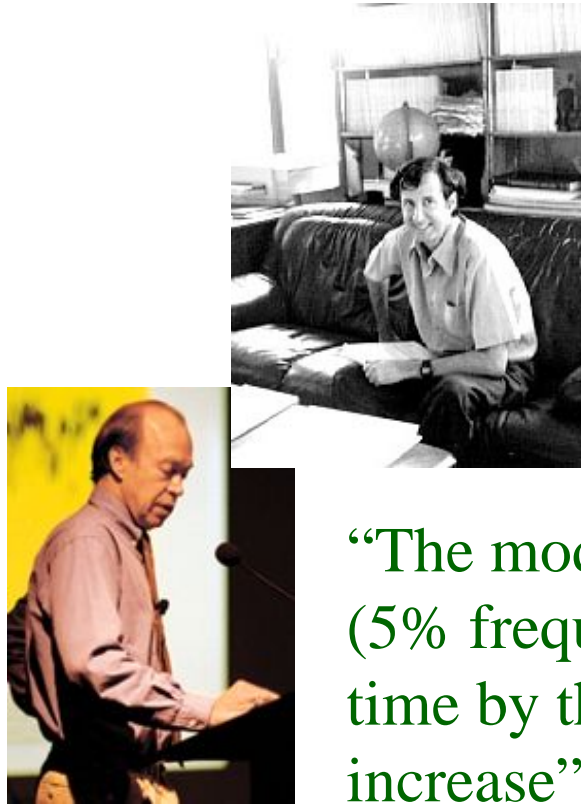
**“Effects of a Carbon Dioxide-Induced Climatic Change on Water Supplies in Western US”
Roger Revelle and Paul Waggoner 1983**

For a hypothetical +2°C warming, and a -10% decrease in precipitation,
the authors empirically estimate the impact on water supplies to be
-76% reduction in the Rio Grande, and a -40% reduction in the Colorado.

***“At present (1983) California depends for about 15% of its water on
imports from the Colorado River....these might be eliminated entirely
with the postulated climatic change”***

“Potential Evapotranspiration and the Likelihood of Future Drought”

David Rind, Jim Hansen et al. 1990, Journal of Geophysical Research



“The model results indicate that severe droughts (5% frequency today) will occur about 50% of the time by the 2050.....due primarily to temperature increase”.

“If droughts of the severity indicated in this study come to pass, global habitability will be seriously affected”

The Colorado River Basin and Climate Change:

The sensitivity of streamflow & water supply to variations in temperature & pcpn

L. Nash and P. Gleick: EPA Report, Policy, Planning and Evaluation 1993



Used the NWS River forecasting model to determine hydrologic consequences in the Colorado Basin to scenarios for climate change

Founder, Pacific Institute

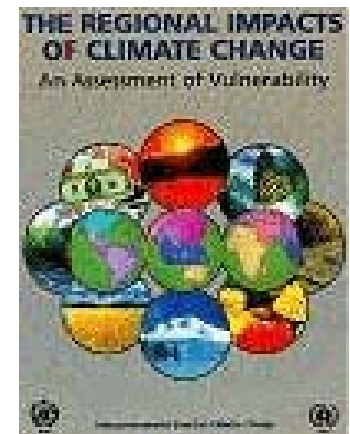
- GCM temperature and pcpn scenarios suggest that pcpn increases would be offset by increased evapotranspiration, with a net effect being a reduction in runoff ranging from 8% to 20%

**“A 20% reduction in natural runoff would cause mean annual reductions in storage of 60 to 70%
reductions in power generation of 60%...”**

Projections from the Second Assessment Report: 1995

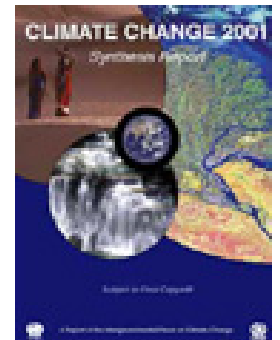
- *Confidence is higher in the hemispheric-to-continental scale projections of climate models than in the regional projections.*
- *There is more confidence in temperature projections than hydrological changes.*
- *Models project an increase in global mean surface air temperature relative to 1990 of about $+1.0^{\circ}\text{C}$ to $+3.5^{\circ}\text{C}$ by 2100.*
- *Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places.*

Potential North American climate change impacts include increased winter/spring runoff and decreased summer soil moisture and runoff.



Projections from the Third Assessment Report: 2001

- *Confidence is increased for continental scale projections.*
- *There is more confidence in temperature projections than hydrological changes.*
- *Models project an increase in global mean surface air temperature relative to 1990 of about $+1.4^{\circ}\text{C}$ to $+5.8^{\circ}\text{C}$ by 2100.*
- *It is likely that summer continental drying and associated risk of drought will increase over most mid-latitude continental interiors.*



*Decreased crop yields, increase forest fire risk,
decreased water quality/quantity.*

*As in SAR though, no specificity on “where” nor “when”
these droughts and their impacts would occur.*

“The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin”

N. Christensen et al. 2004 Climatic Change



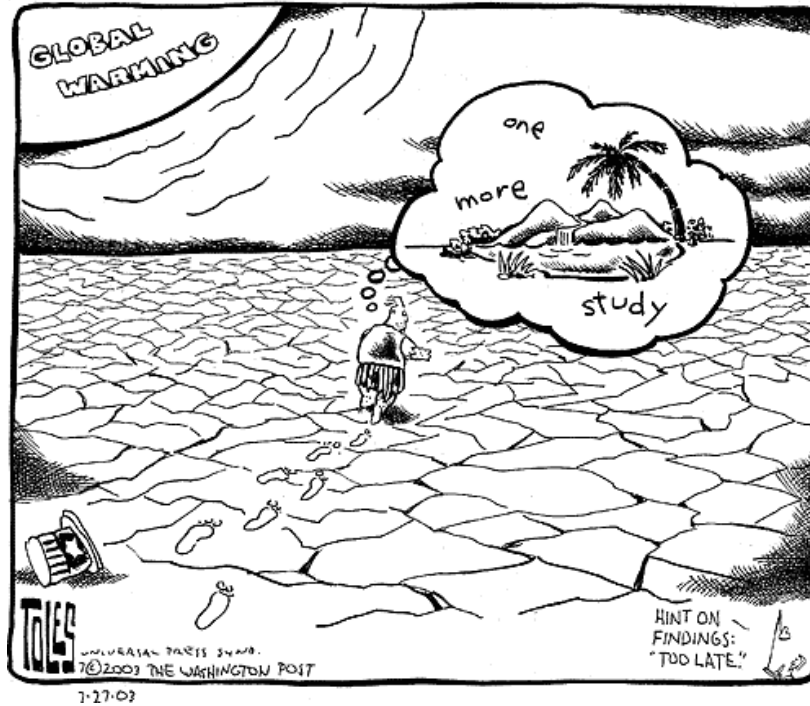
Land Surface Hydrology Research Group, UW

Used GCM output to drive the Variable Infiltration Capacity (VIC) macroscale hydrology model to produce corresponding streamflow sequences

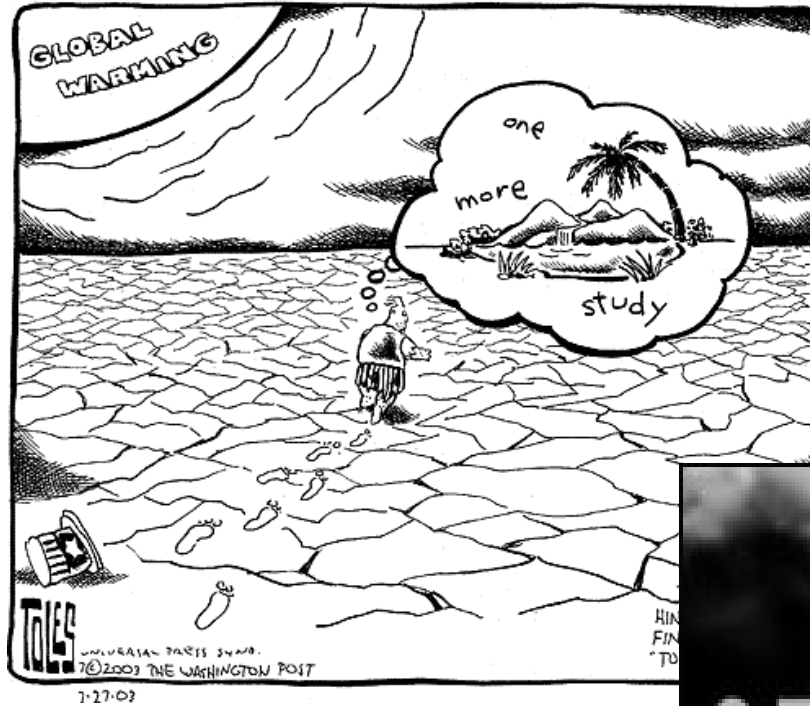
**At 2050, Colorado River flow would decline -18%,
largely due to a +1.7°C projected warming.
Average Colorado Basin water storage would decline by 32%.**

Note: It is now known that the global model used in the Christensen et al. study was one of the least sensitive regarding response of temperature to increasing greenhouse gases.

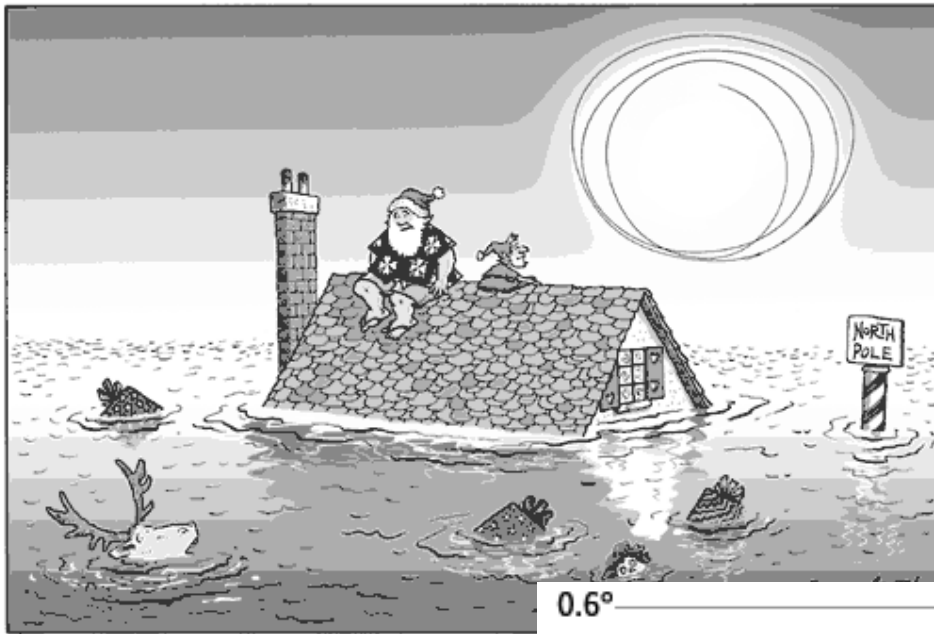
Barriers to grasping the hydrologic consequences of climate change



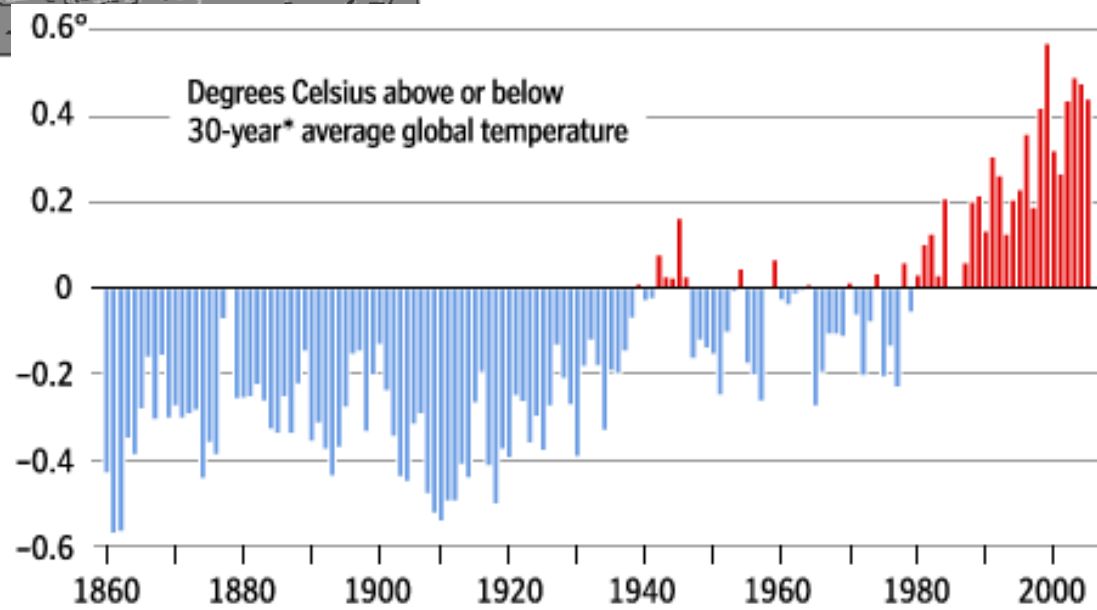
Barriers to grasping the hydrologic consequences of climate change



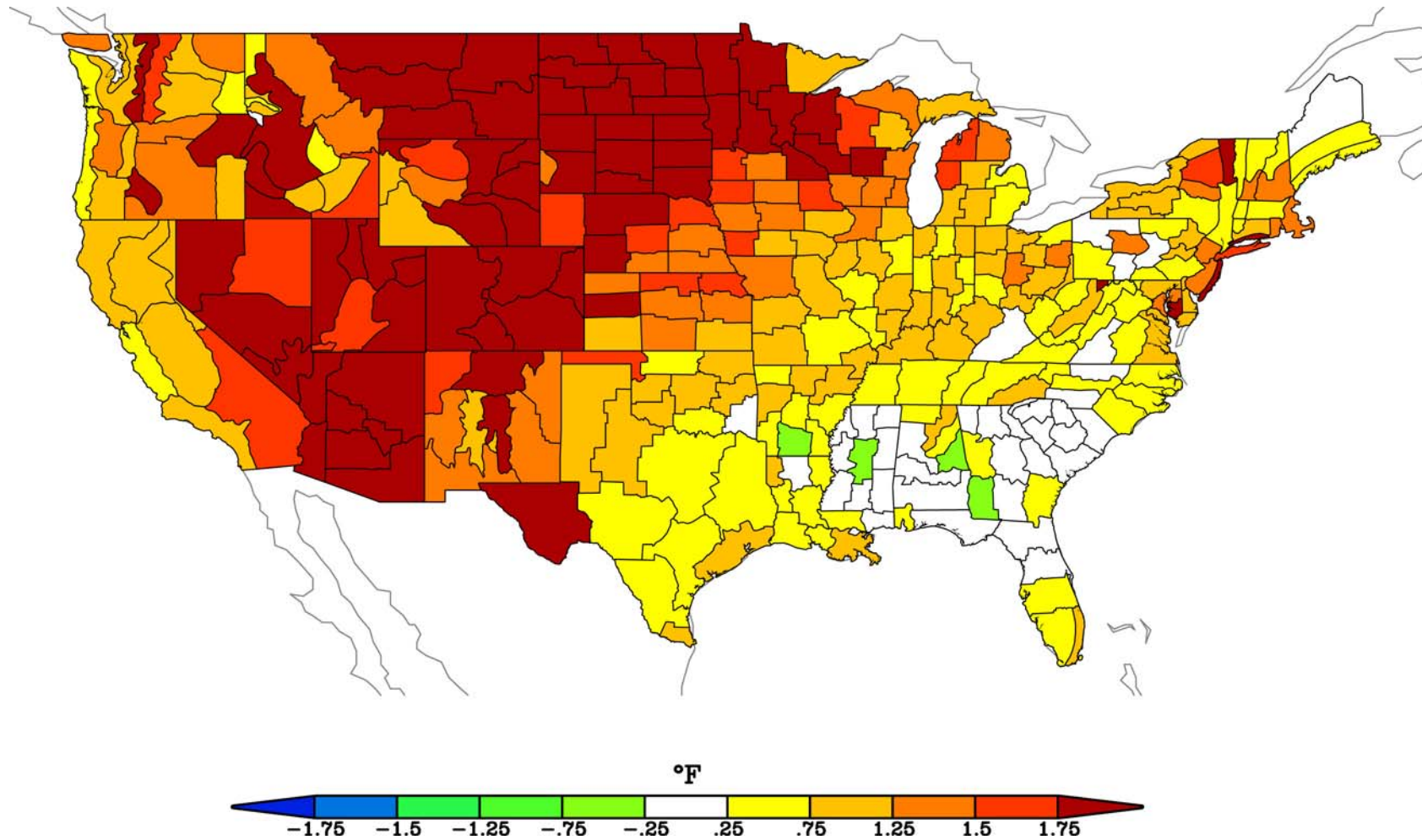
Barriers washing away.....



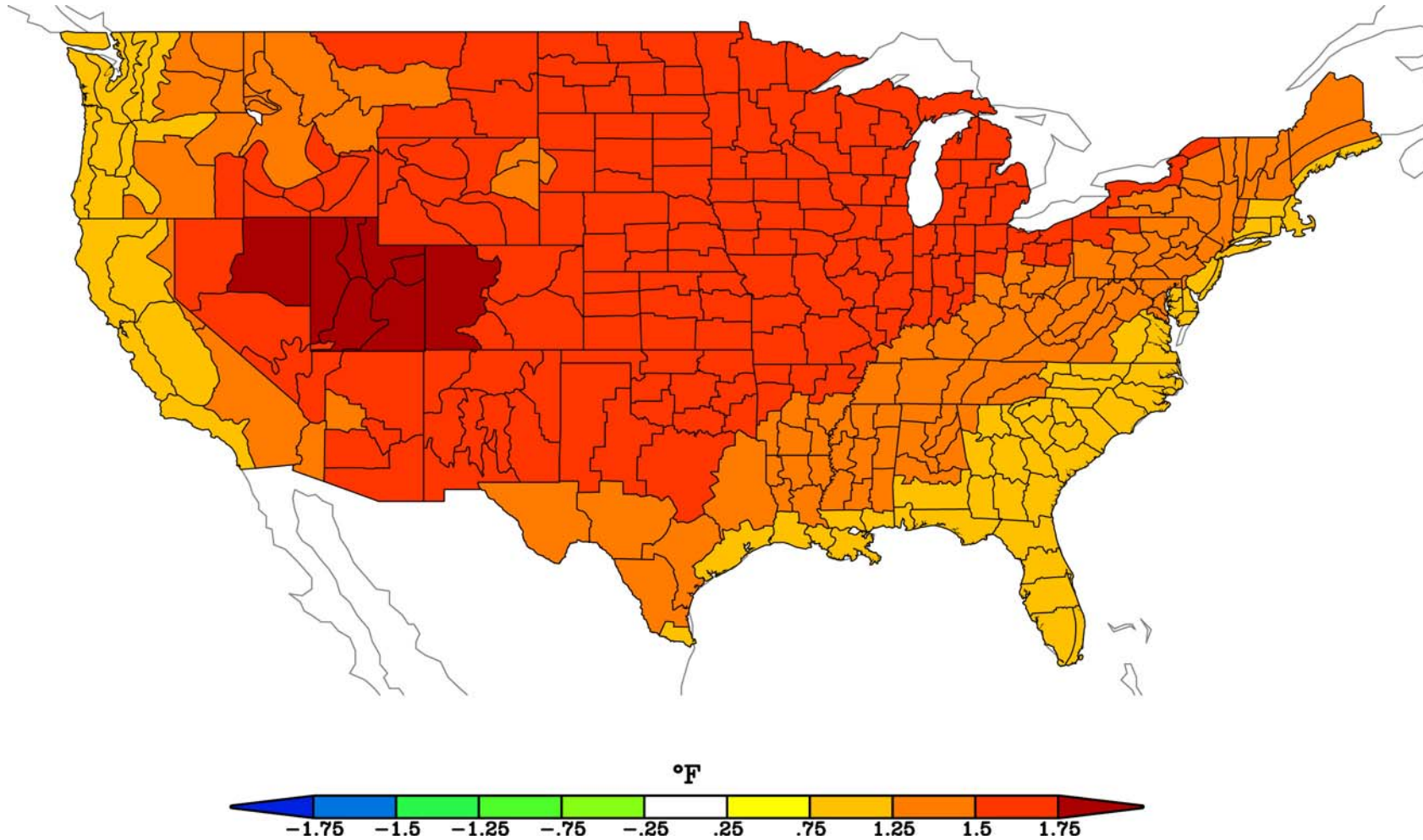
12-23-05 THE AMERICAN INQUIRER, INTERVIEW WITH SWINGGARD.



Observed Annual Temperature Anomaly 2000-2006



IPCC (AR4) Simulated Annual Temperature Anomaly 2000-2006



Strategies in the Face of Uncertainty



IPCC-AR4 Climate Model Simulations

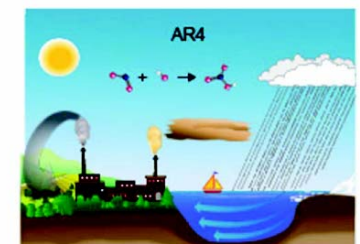
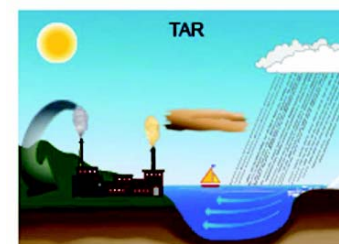
Anthropogenic and Natural Forcings

- ❑ Simulation production for 1895-2005
- ❑ Specified monthly varying ANTH/NAT Frg 1895-2000
- ❑ A1B Scenario 2001-2060
- ❑ 18 Different Coupled Models/42 total runs
- ❑ Experiments are part of the IPCC AR-4 Suite

http://www-pcmdi.llnl.gov/ipcc/about_ipcc.ph



Rajendra K. Pachauri-IPCC Chair
IPCC Fourth Assessment Report,
Climate Change 2007 to be issued in 2007



“Global pattern of trends in streamflow and water availability in a changing climate”

C. Milly et al. 2005 Nature US Geological Survey, Geophysical Fluid Dynamics Laboratory/NOAA



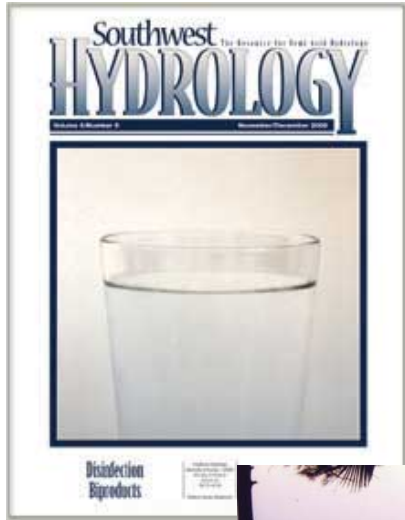
Analyzed the change in runoff from 12 of the AR4 IPCC models

These models project 10-30% decreases in runoff in western North America by the year 2050

“Such changes in sustainable water availability would have considerable regional-scale consequences for economies as well as ecosystems”

“Past Peak Water in the West”

M. Hoerling and J. Eischeid 2007 Southwest Hydrology



**Calculated the change in drought intensity over the US
for the next 50 years using data from
18 AR4 IPCC models**

- *Air temperatures are virtually certain to warm further
in coming decades*

*Warmer air temperatures would greatly increase
drought severity and reduce water resources*



**“The Southwest is likely now past the peak water experienced in the
20th century : a decline in Lees Ferry flow will reduce water
availability below current consumptive demands within a mere 20yrs.**

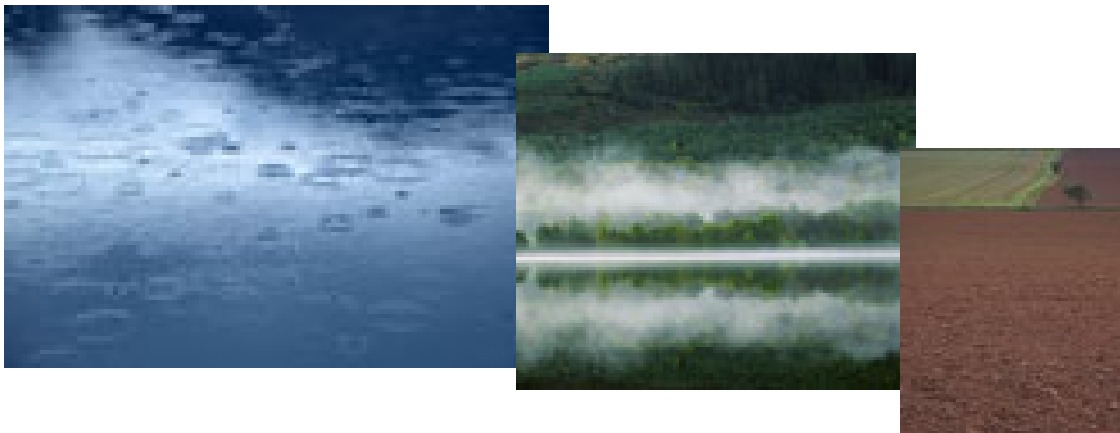
Drought Defined

Drought is an *imbalance between precipitation and evapotranspiration*

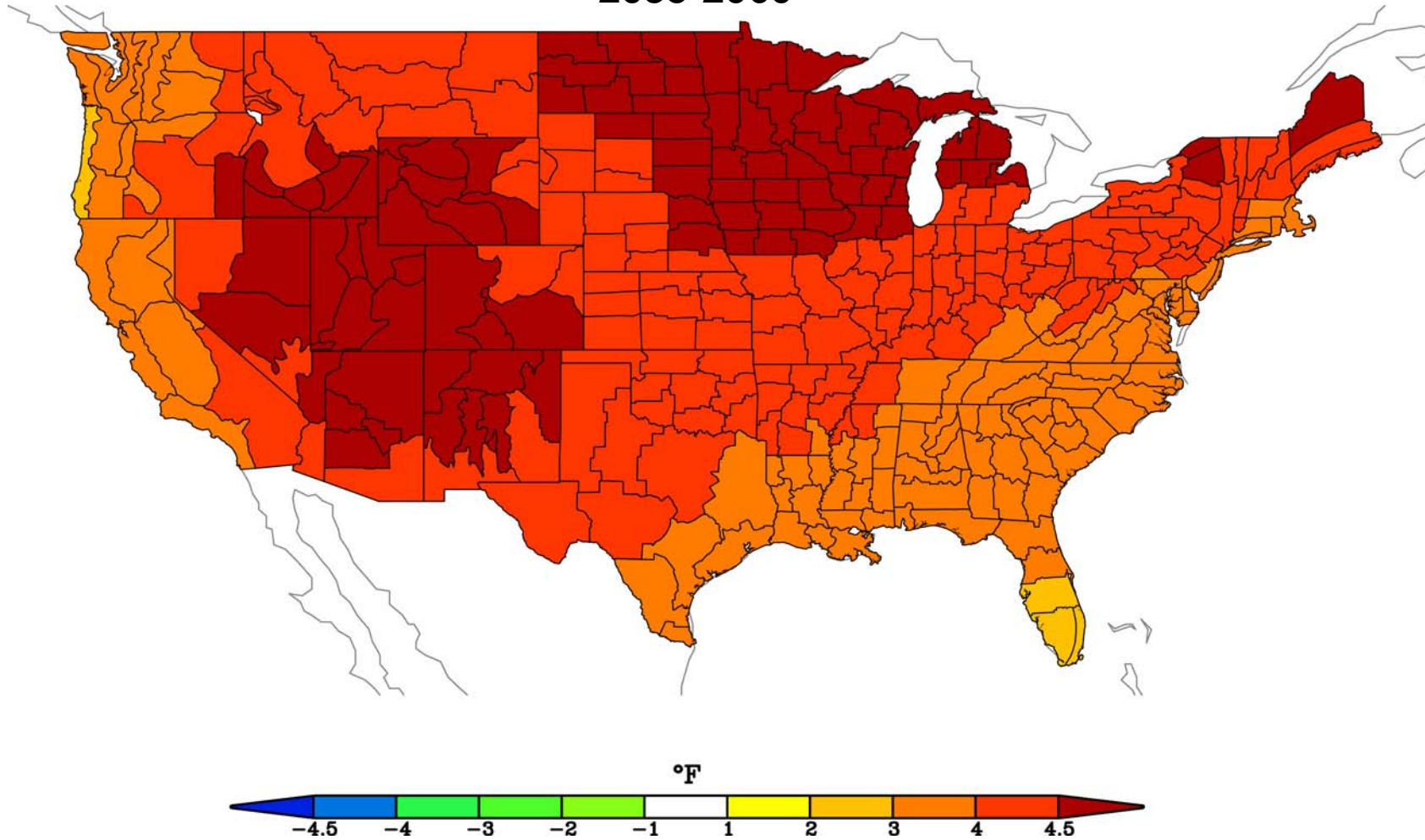
A meteorological drought develops when moisture demand due to potential evapotranspiration exceeds the supply available from precipitation and soil moisture.

PDSI < -3 denotes “severe drought”

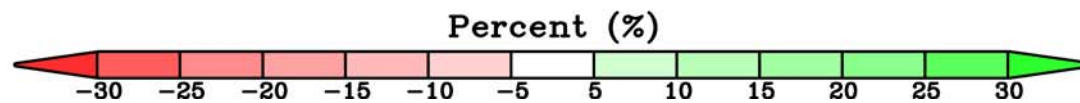
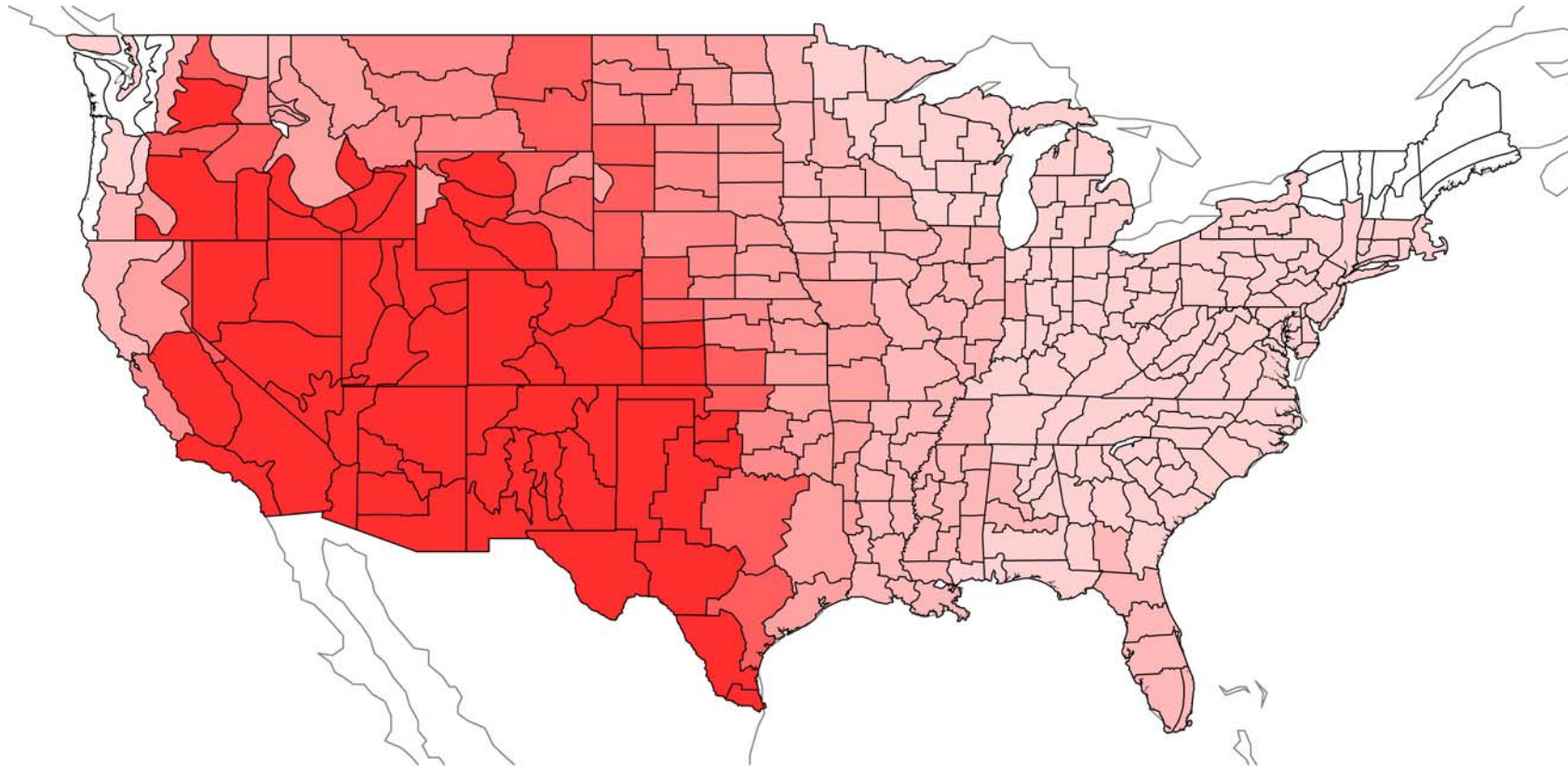
(Palmer 1965, Thornthwaite 1948)



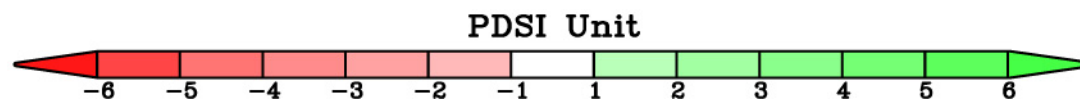
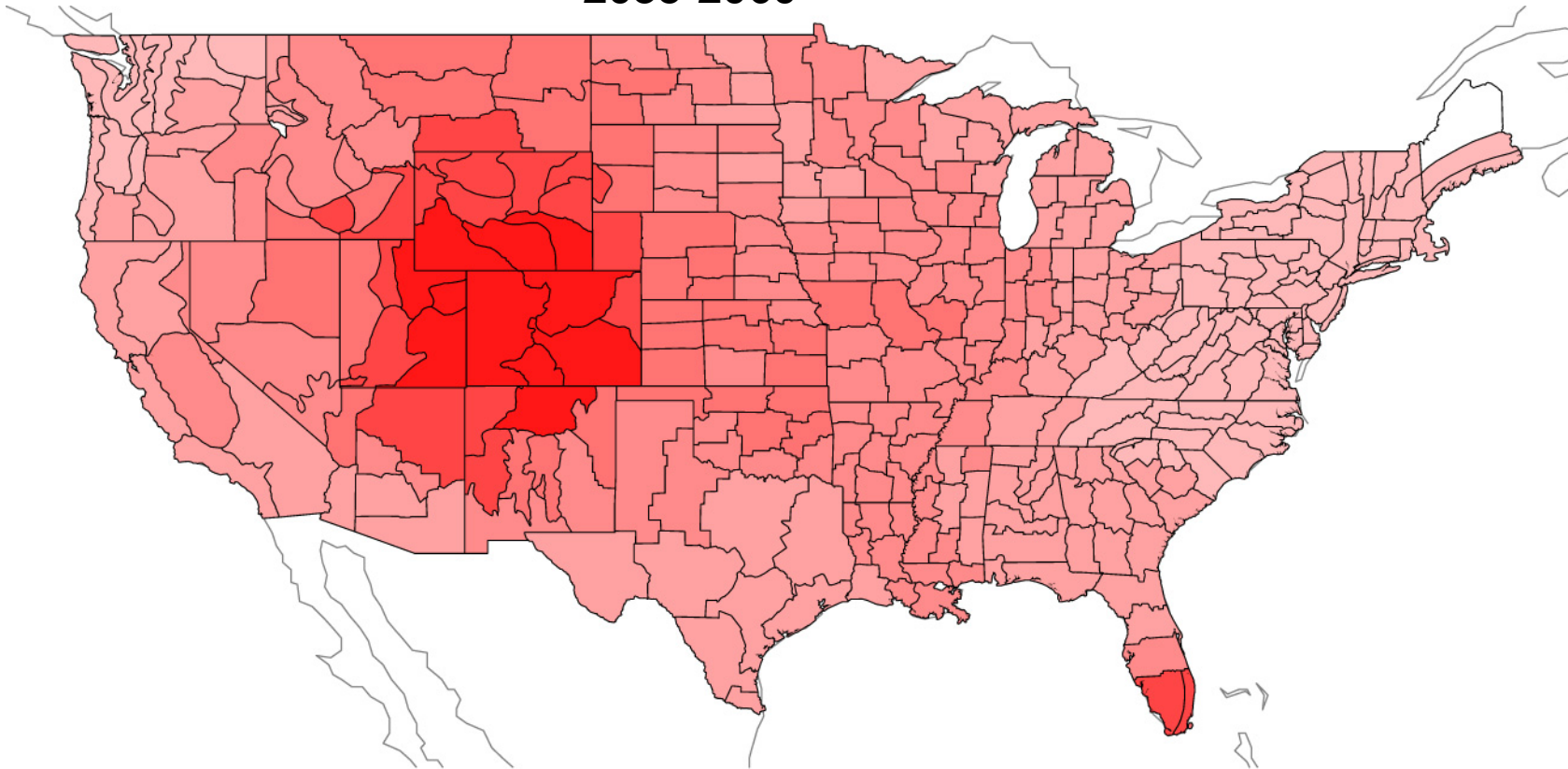
Change in Annual Temperature 2035-2060



Change in Annual (PCPN-Potential Evapotranspiration) 2035-2060



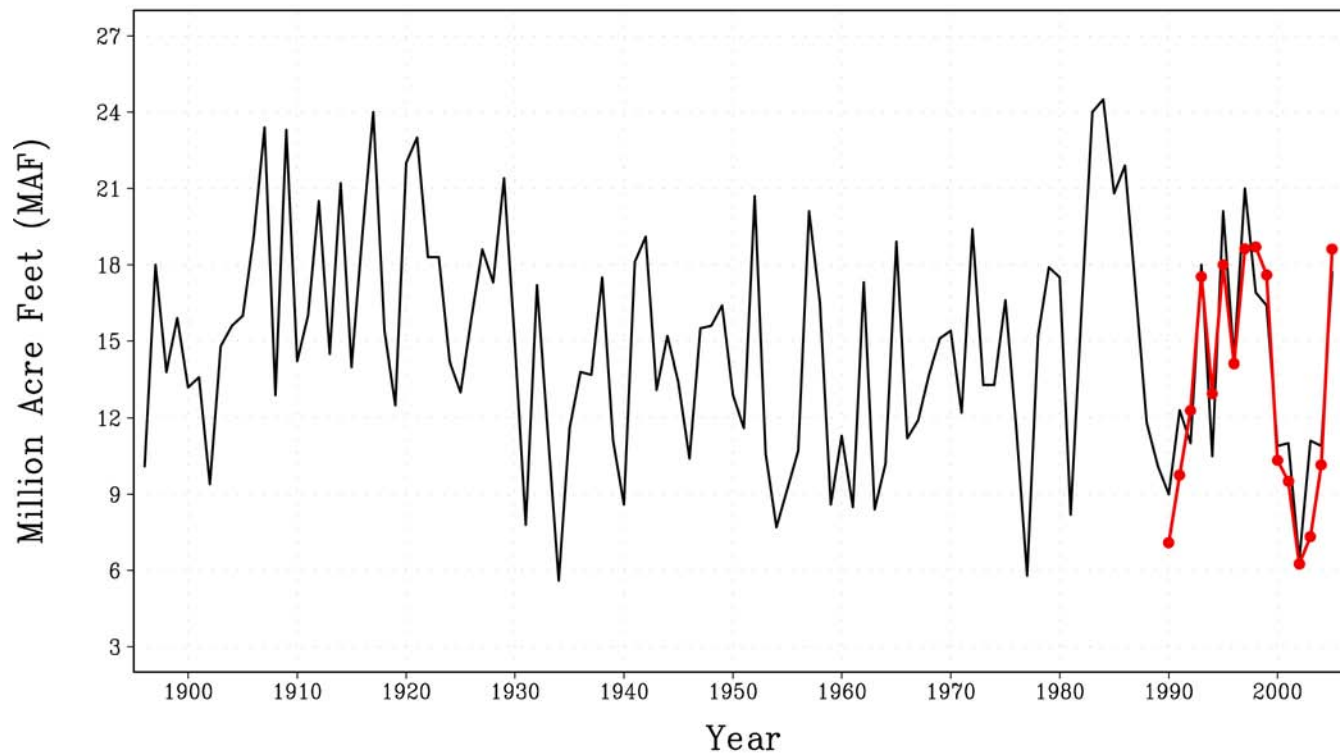
Change in Palmer Drought Index 2035-2060



Downscaling Water-Shed Drought to Gauge Streamflow

Upper Colorado River Flow at Lee Ferry

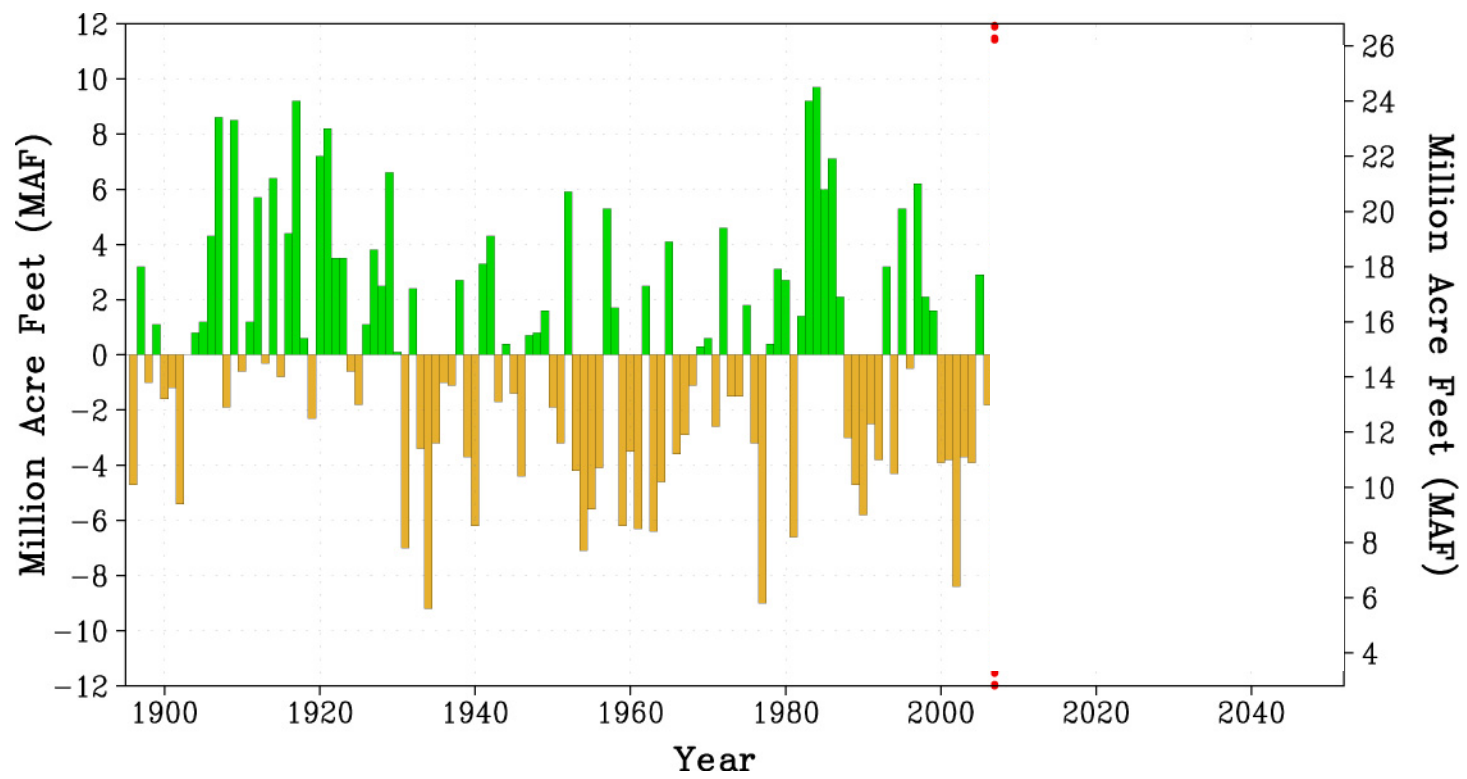
$$\text{flow} = 1.69(\text{pdsi}) + 14.5, R=0.79, R^2=62.5\%$$

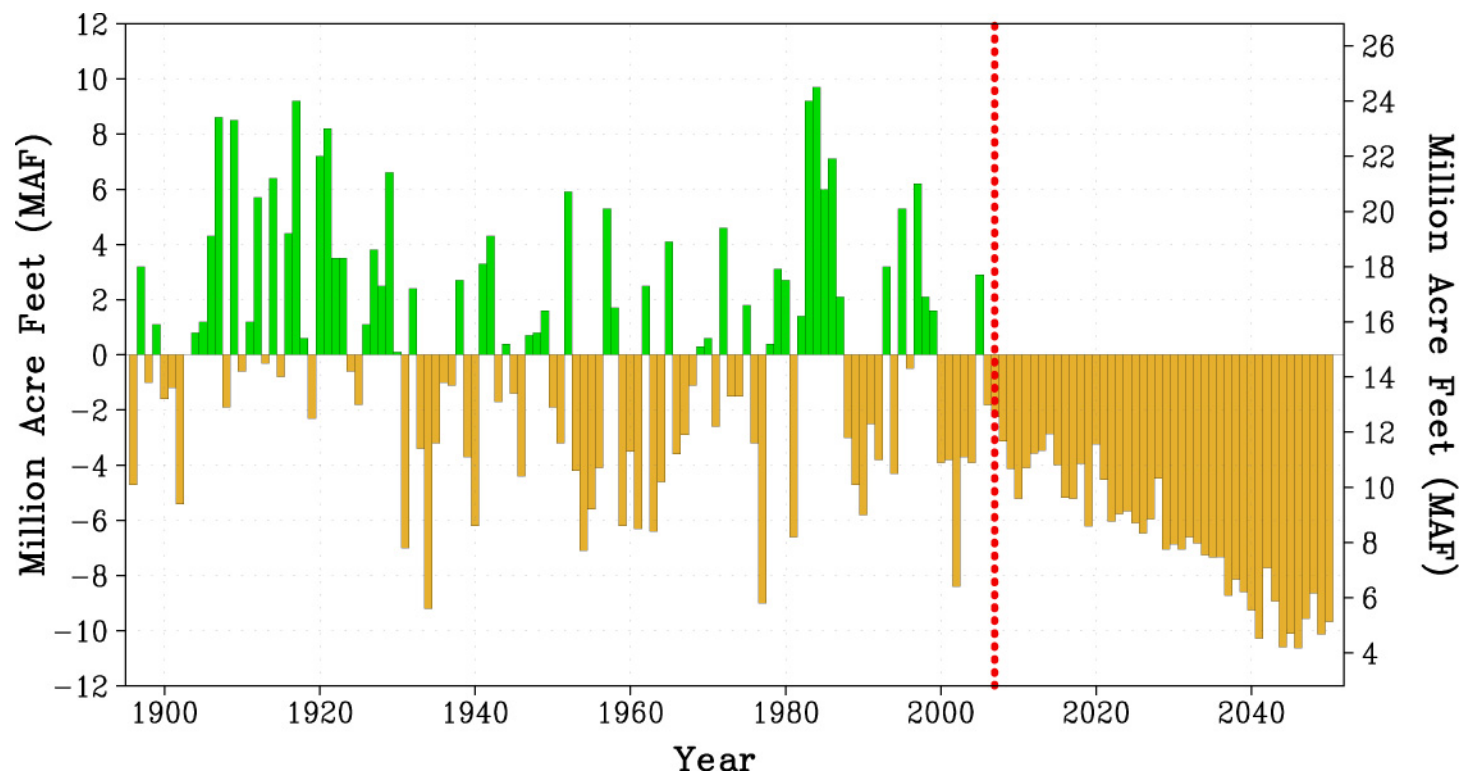


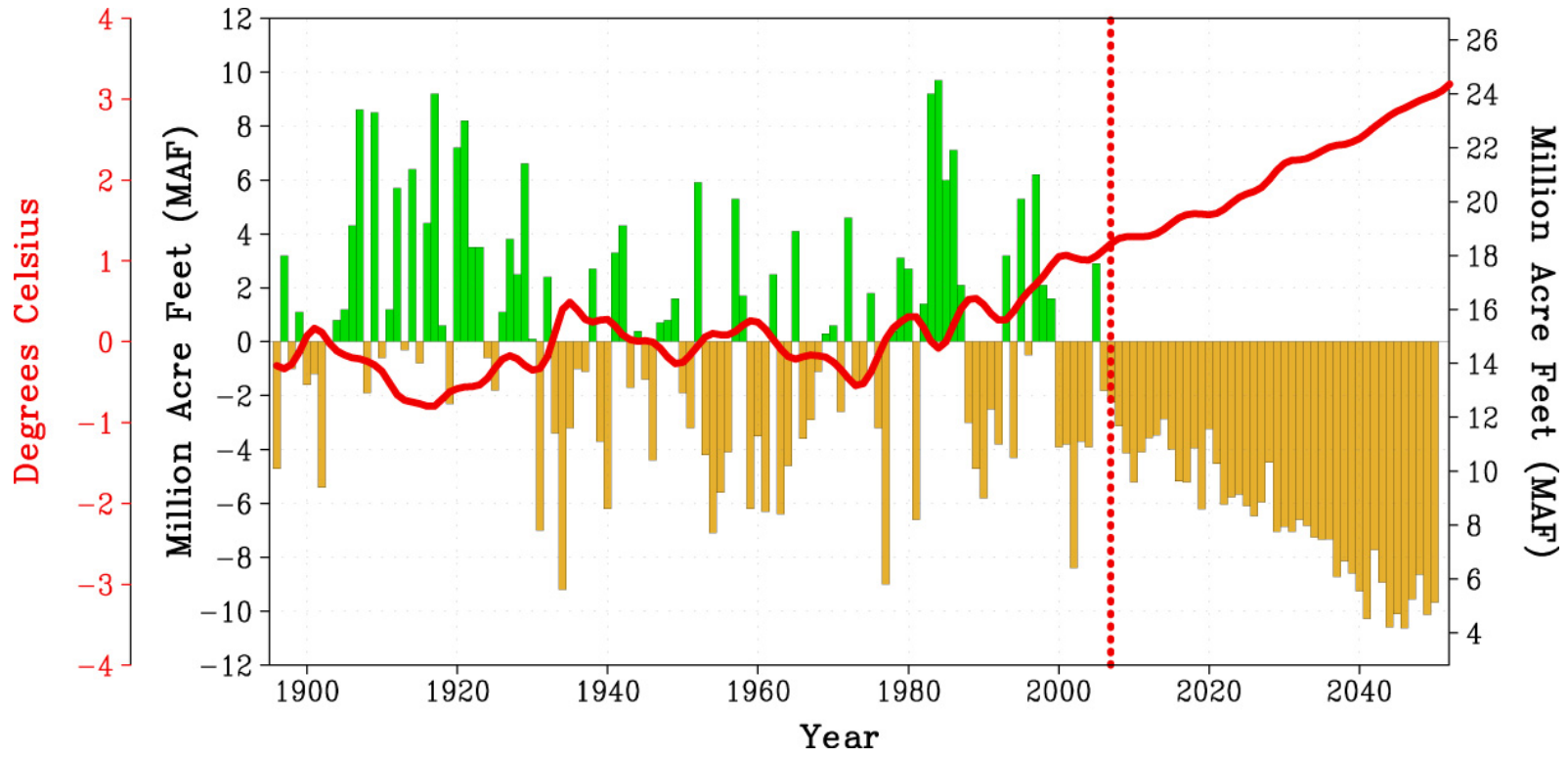
— 1895–1988 (n=94) training period

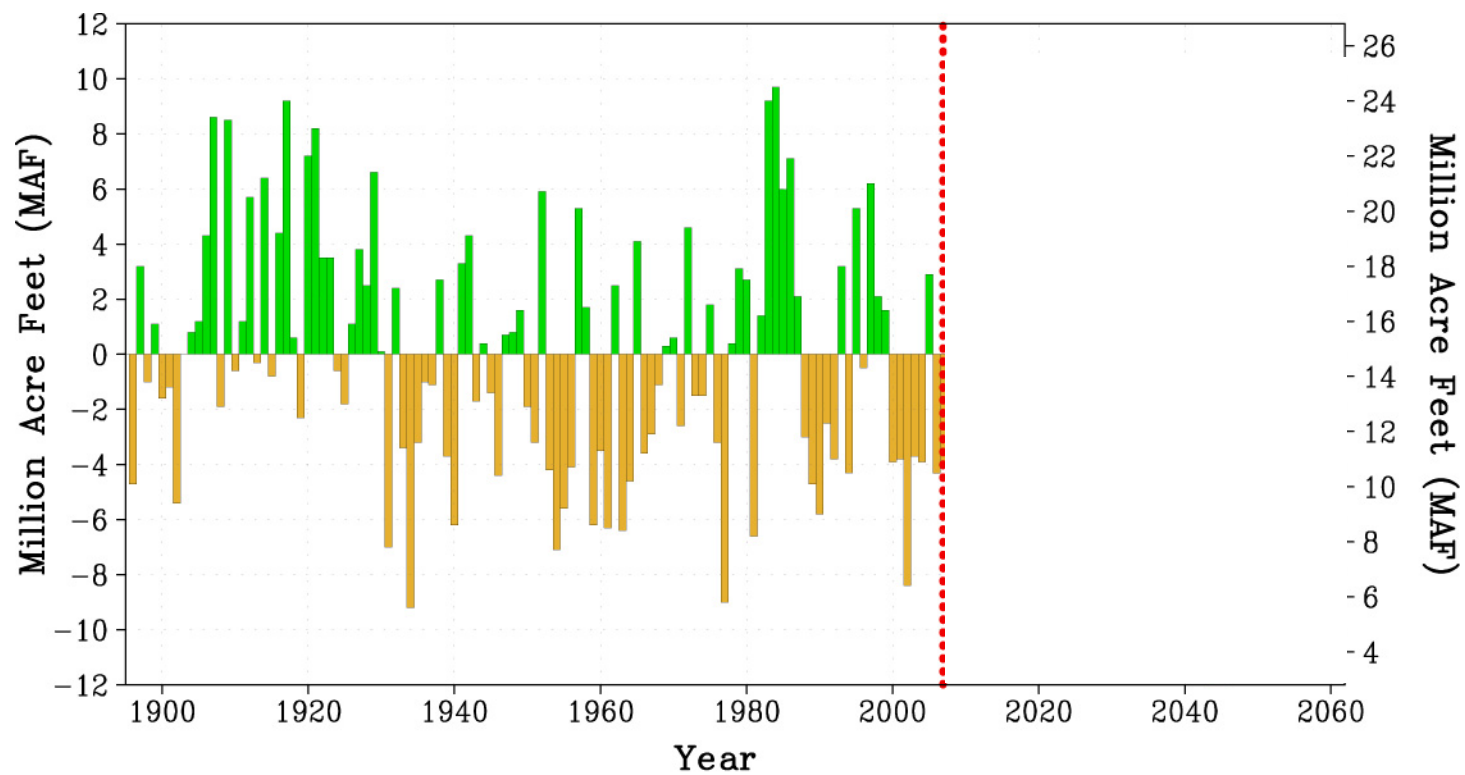
— 1989–2005 verification period

Projected Streamflow Change at Lees Ferry

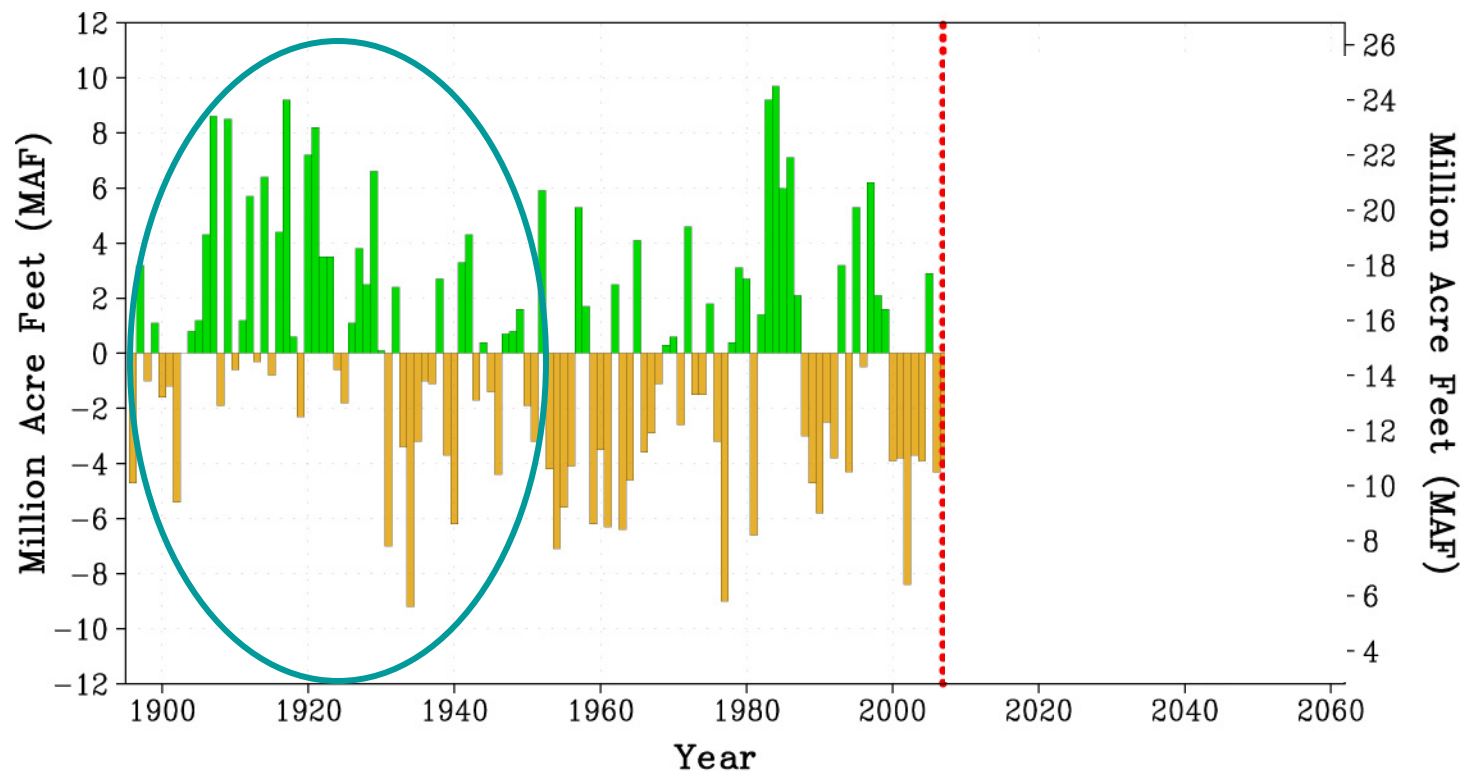




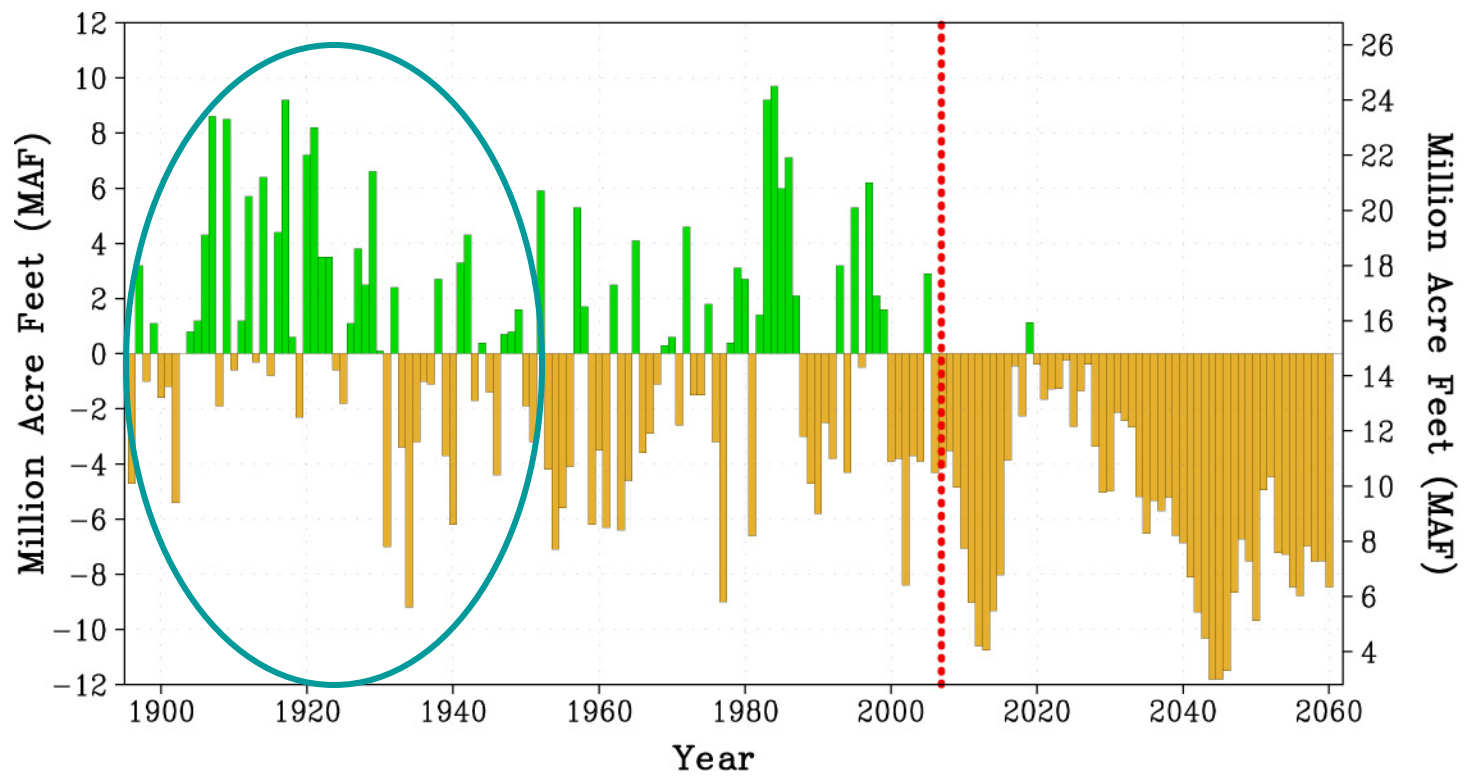




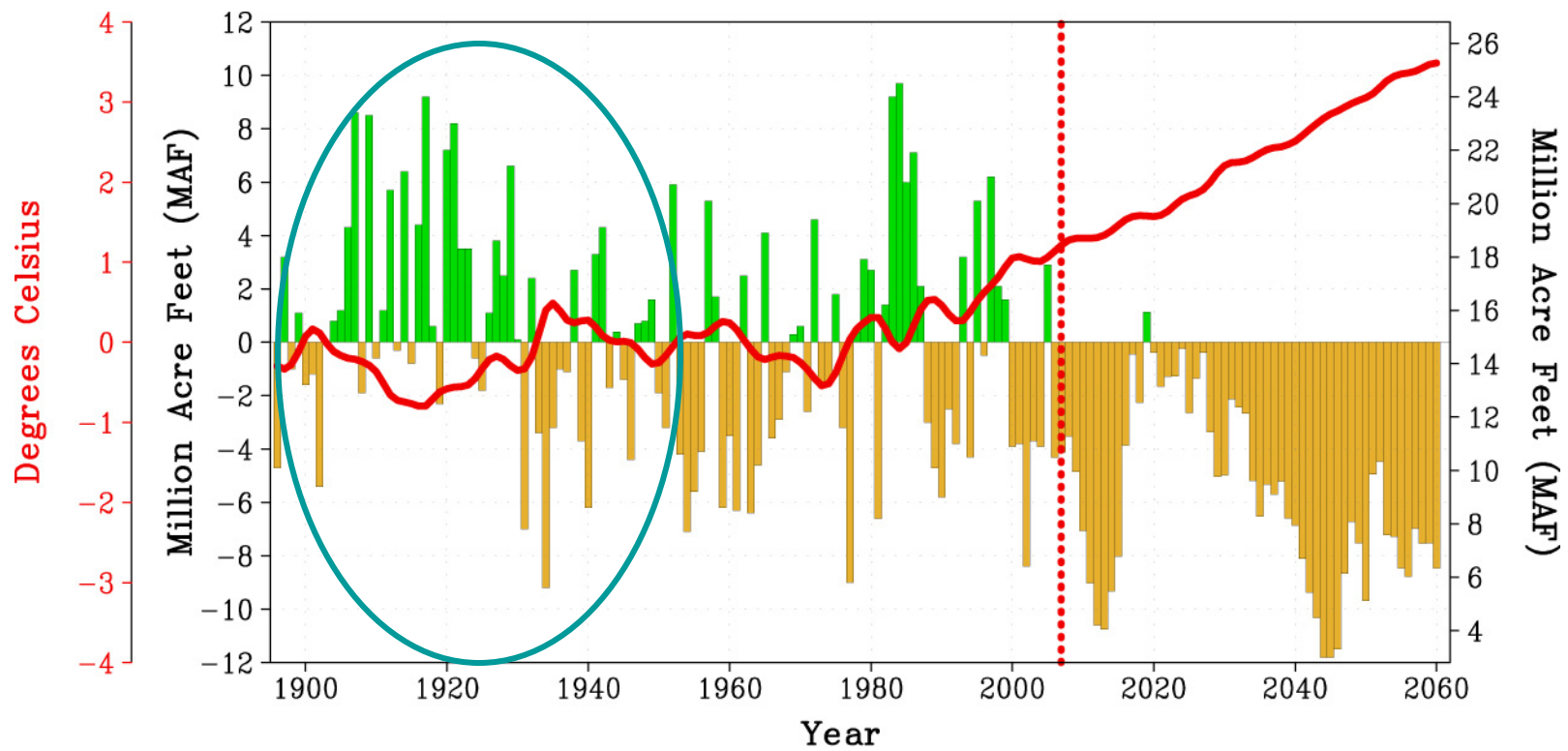
AR4 Proj Tmp, Obs PcP data 1896–1950



AR4 Proj Tmp, Obs PcP data 1896–1950



AR4 Proj Tmp, Obs PcP data 1896–1950



AR4 Proj Tmp, Obs PcP data 1896–1950

Waggoner: Scientists to share what is known, to be likely to be known soon, and what will likely remain uncertain, in societally relevant context

Key Points

- *Air temperatures are virtually certain to warm further*
- *Warmer air temperatures would probably severely reduce the quantity of water resources*

The semi-arid and arid West is found to be at greatest risk. It is likely that Lees Ferry flow will decline below 20th Century consumptive uses within a few decades

